Dual-Phase Argon Detector Development at LLNL

S. Sangiorgio, A. Bernstein, C. Hagmann, P. Sorensen,
S. Pereverzev, K. Kazkaz, V. Mozin (LLNL)
J. Coleman, K. Mavrokoridis (U. of Liverpool)
T. Joshi (LLNL, UCB)
I. Jovanovic, M. Foxe (PSU)

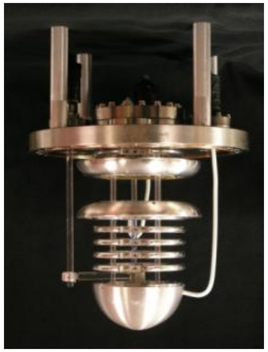
Lawrence Livermore National Laboratory

Workshop on
Low Threshold Detectors for Detection of Coherent Neutrino Scattering

Dec 06, 2012

LLNL-PRES-609983
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

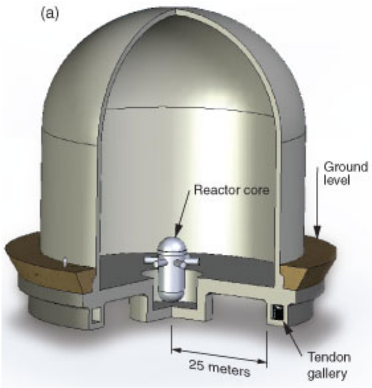
Overview of LLNL experimental program on LAr



- **Single-phase detector [2007 – 2010]**
  - Understand the gaseous region of the proposed dual-phase detectors
  - Pulse Shape Modeling

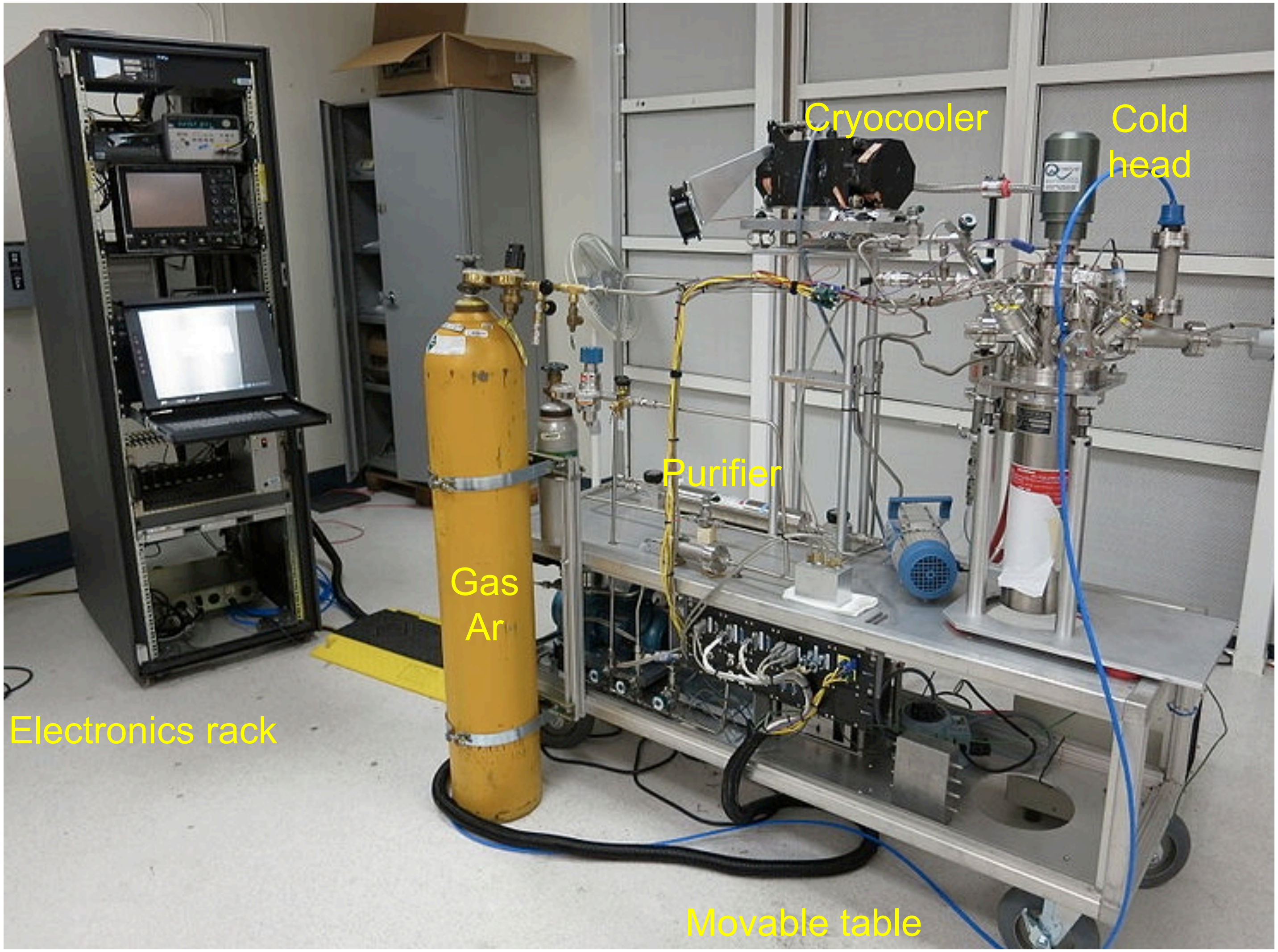
- **Small (~100 g) dual-phase detector [since 2010]**
  - Develop an understanding of dual-phase detector design and operation
  - Study the ionization yield of nuclear recoils in liquid argon

More details in M.Foxe and T.Joshi talks



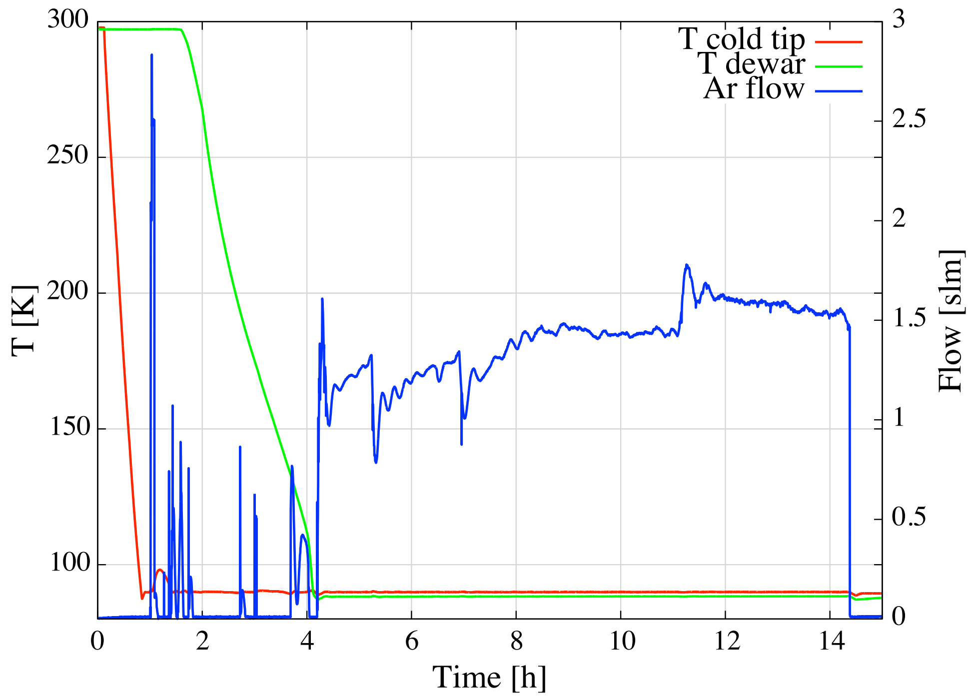
- **Large (10 kg) dual-phase detector**
  - Study and suppress backgrounds
  - Deployment at a reactor. Look for variation of CNS signal due to outages
  - Detection of CNS!

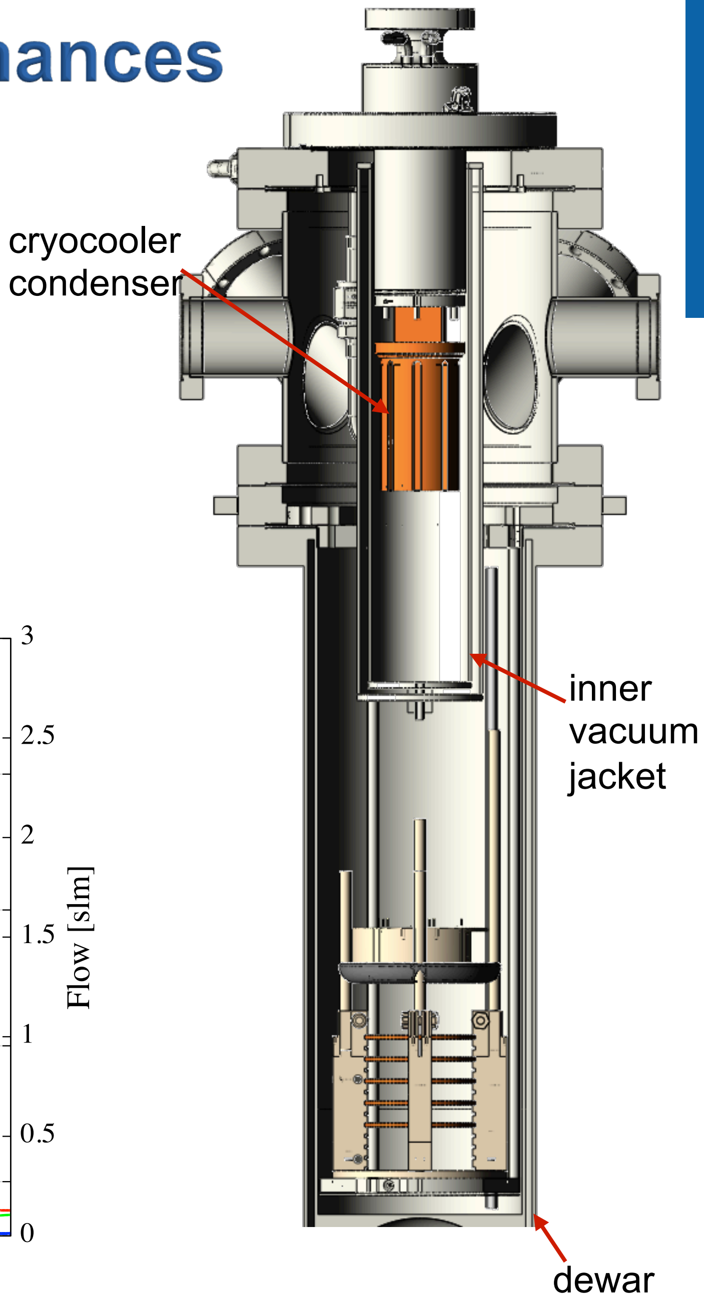
The Dual-Phase LAr Setup



Cryogenic Operation & Performances

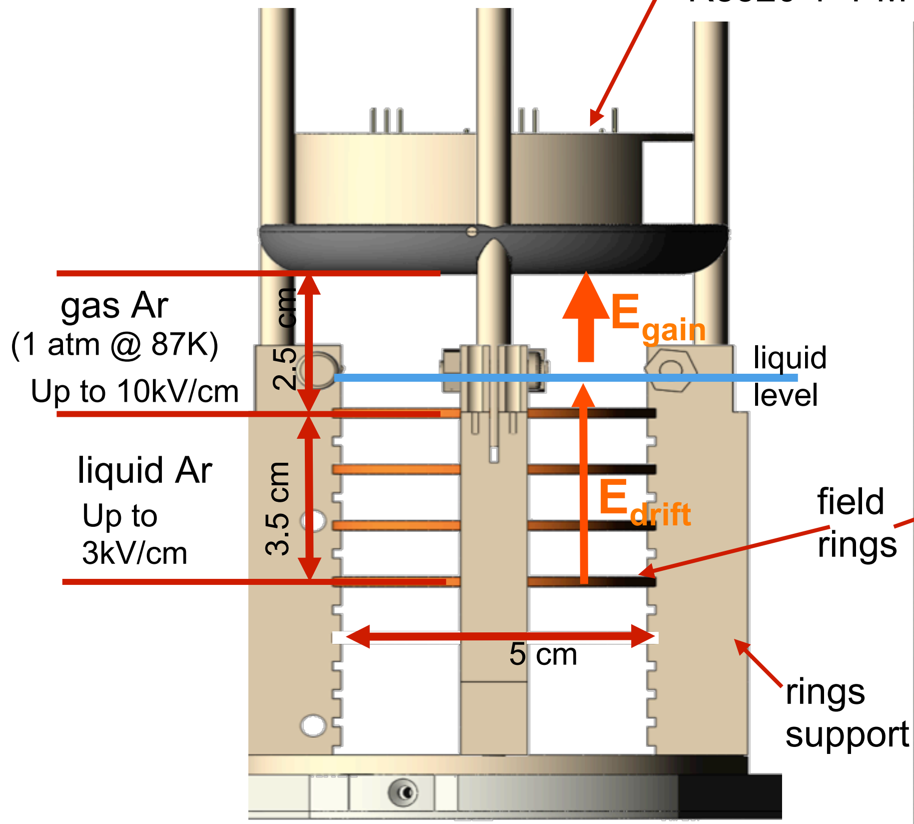
- In-situ production of LAr w/ cryocooler
- Automated cooldown and liquefaction in ~14h
- Temperature stability ± 0.05 K
- Total ~1 liter of Argon can be circulated 3-4 times per day

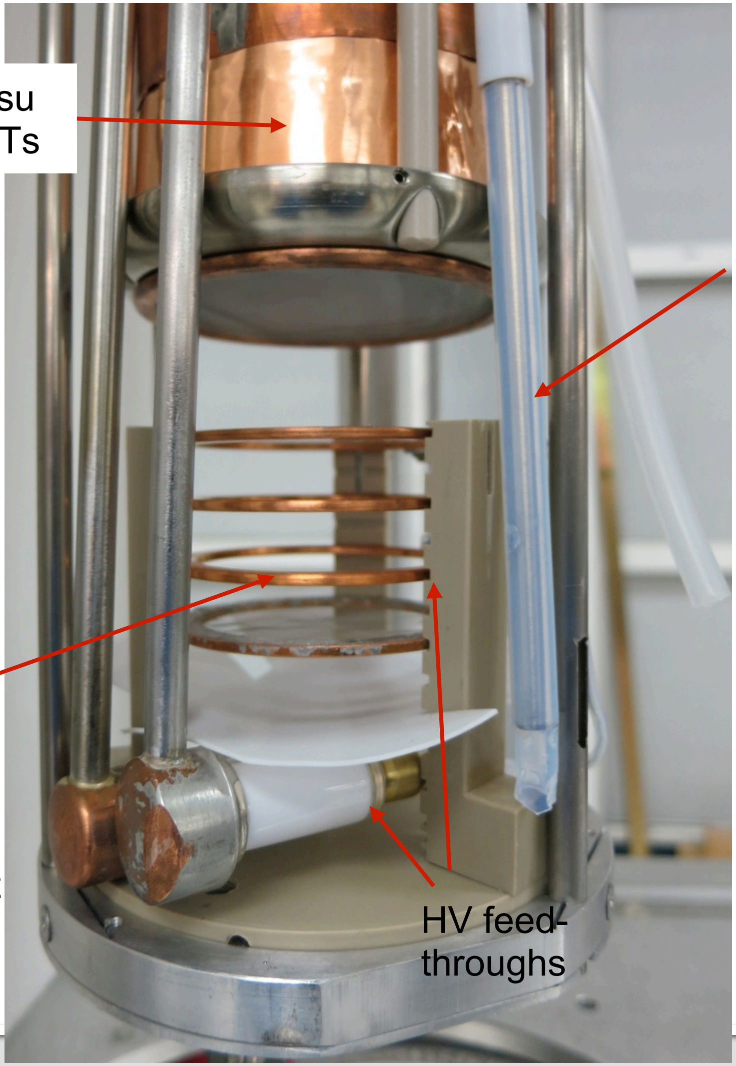




LLNL Dual-phase Ar Prototype Detector

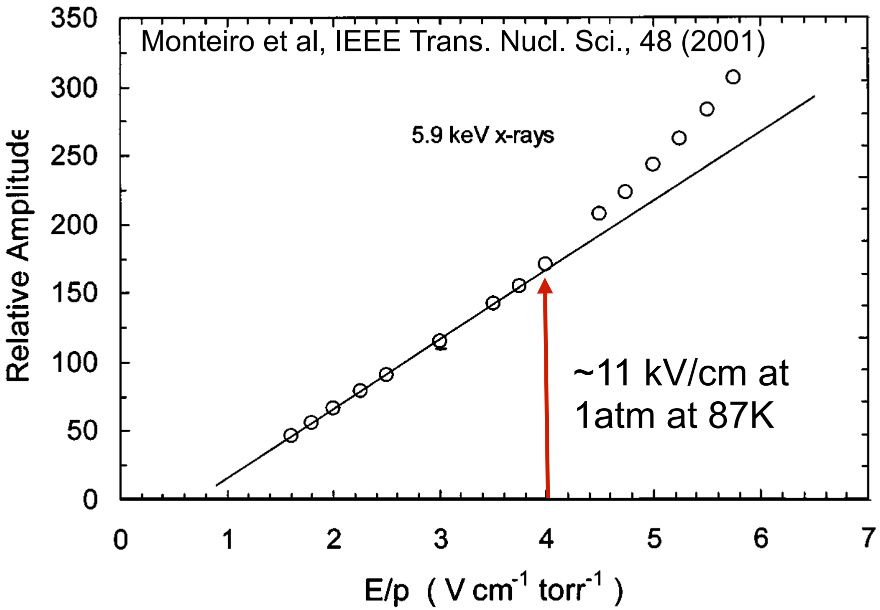
- Active volume: ~ 100 g LAr
- Materials selected for low outgassing
- TPB as wavelength shifter
- Home-built HV feedthroughs

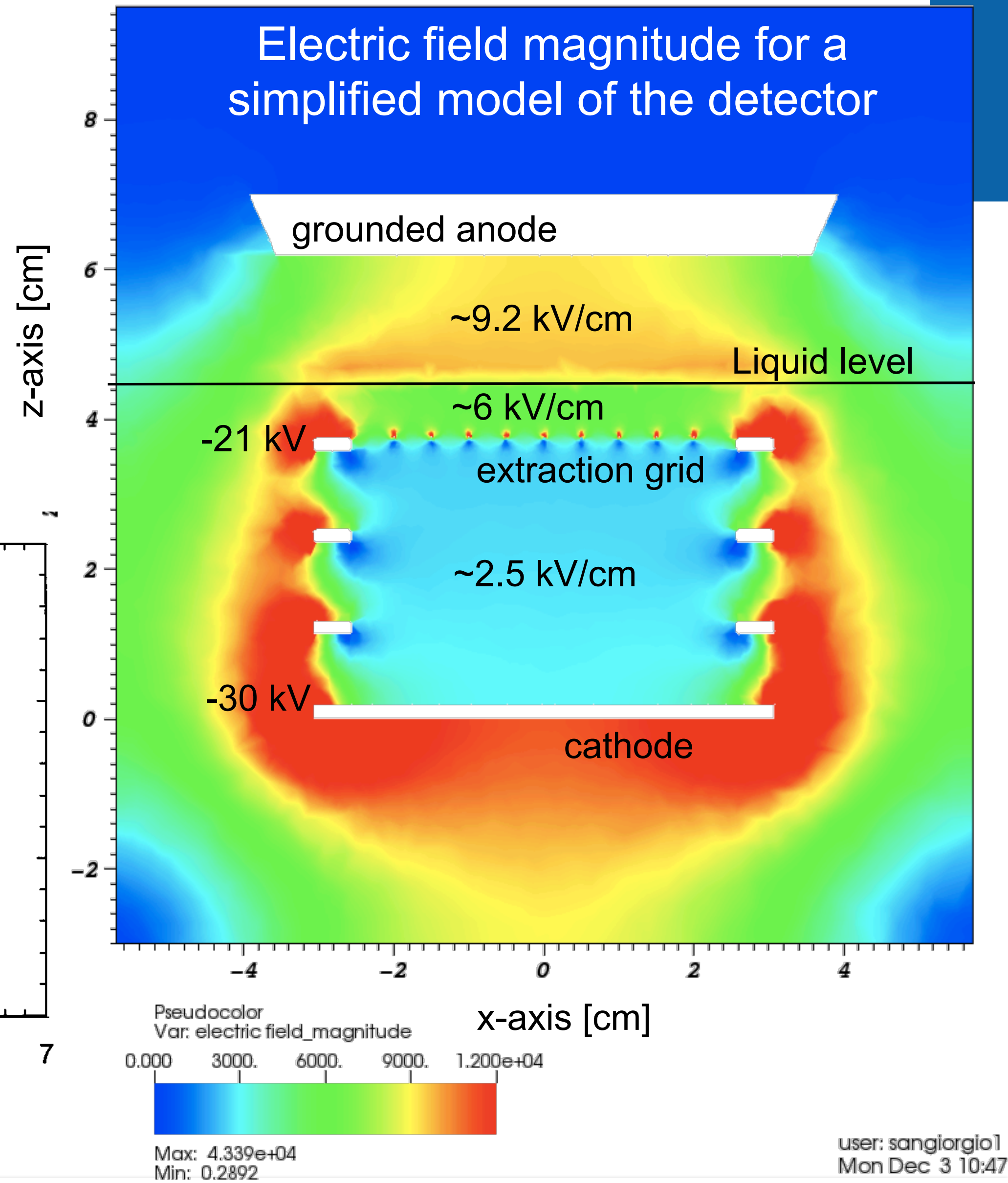




High Gain Detection of Ionization Signal

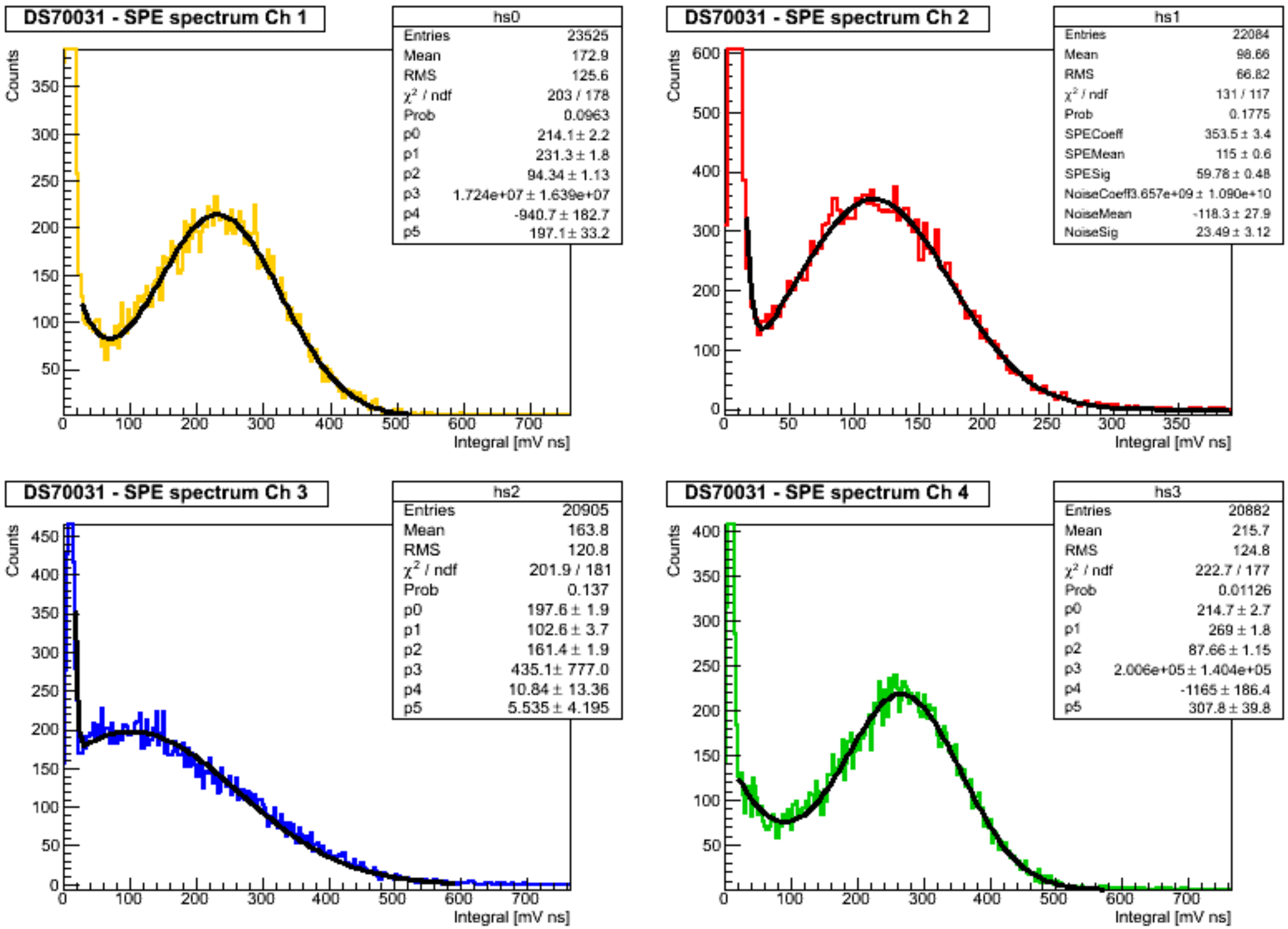
- Emphasis on detection of ionization by means of S2 only
- Operate close to electron multiplication in gas





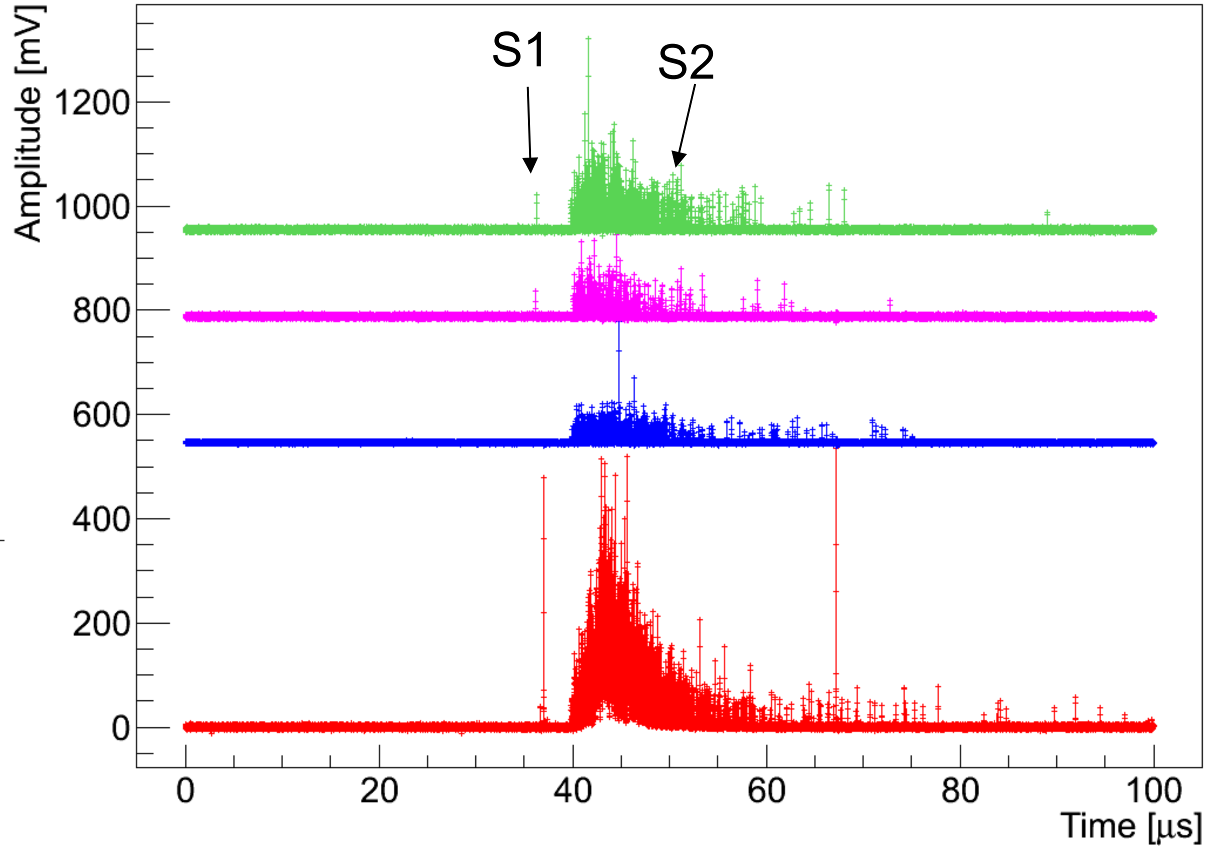
PMTs S.P.E. Response

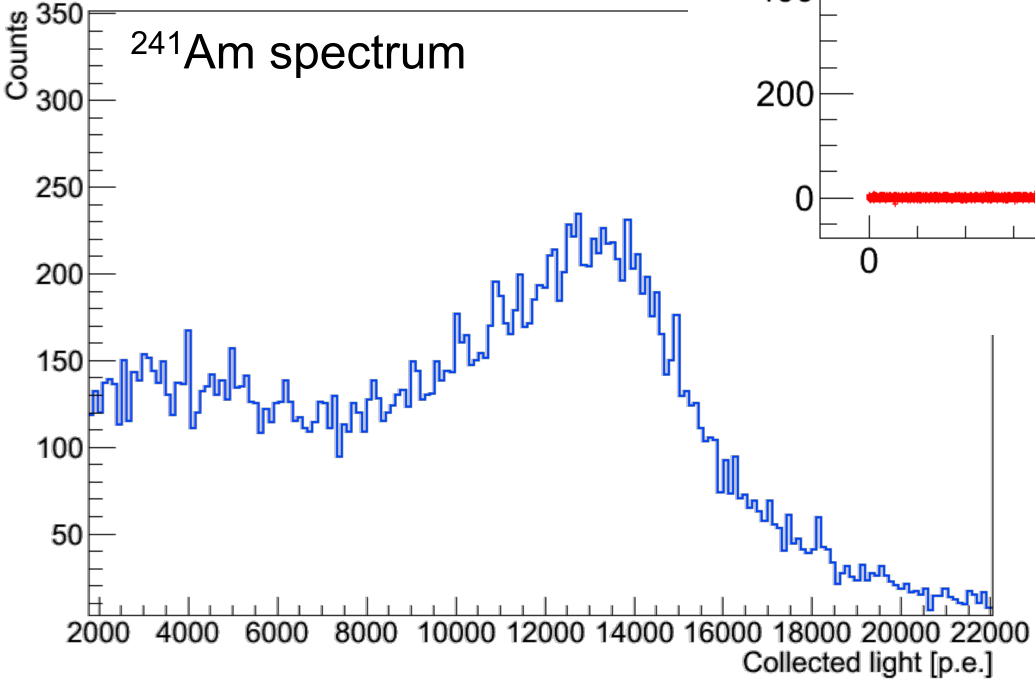
Hamamatsu R8520 1" PMTs for cryogenic operation



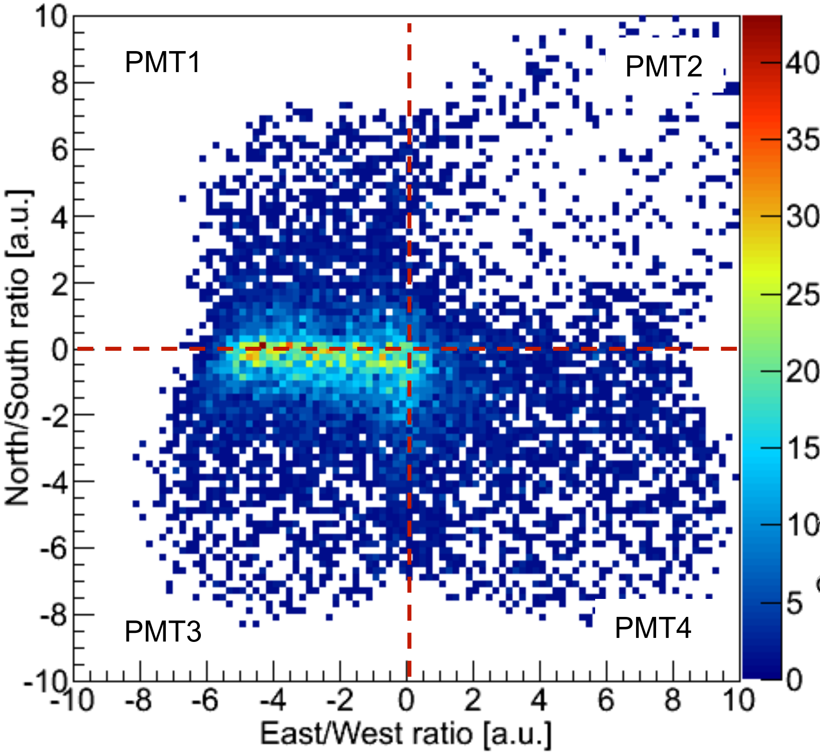
Detector Response

Sample event from a 60 keV photoelectric interaction in the detector as seen by the 4-PMT array

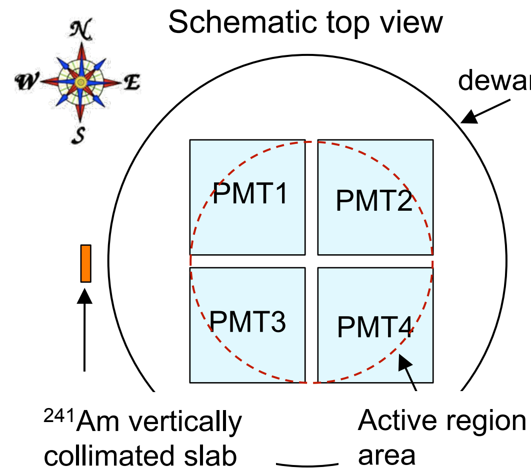




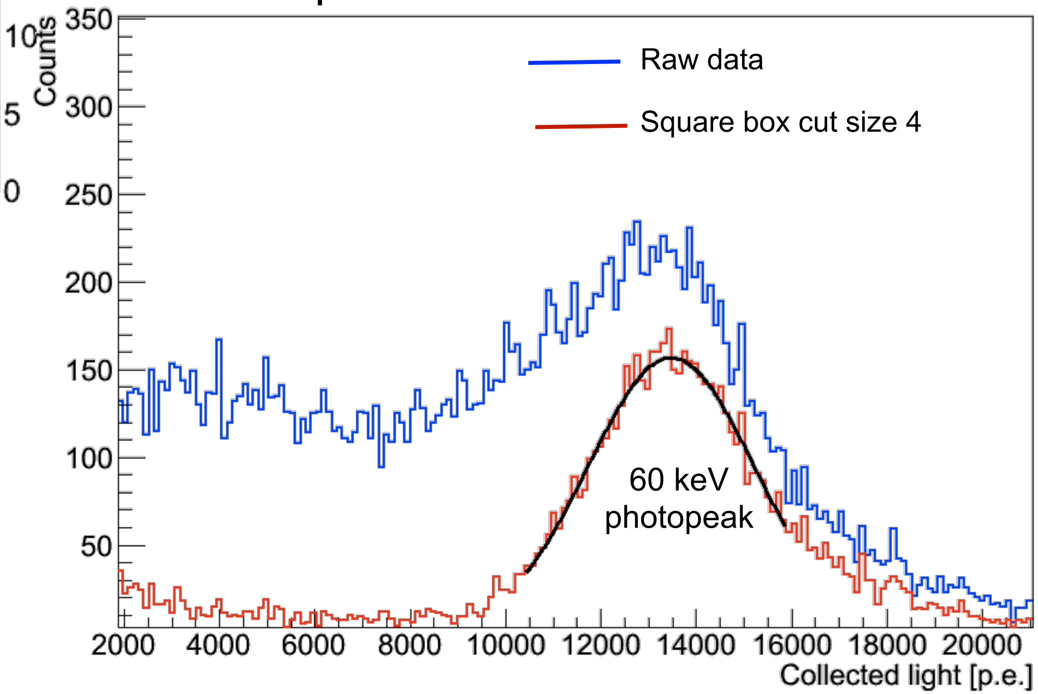
Event Localization



^{241}Am spectrum fiducial plot



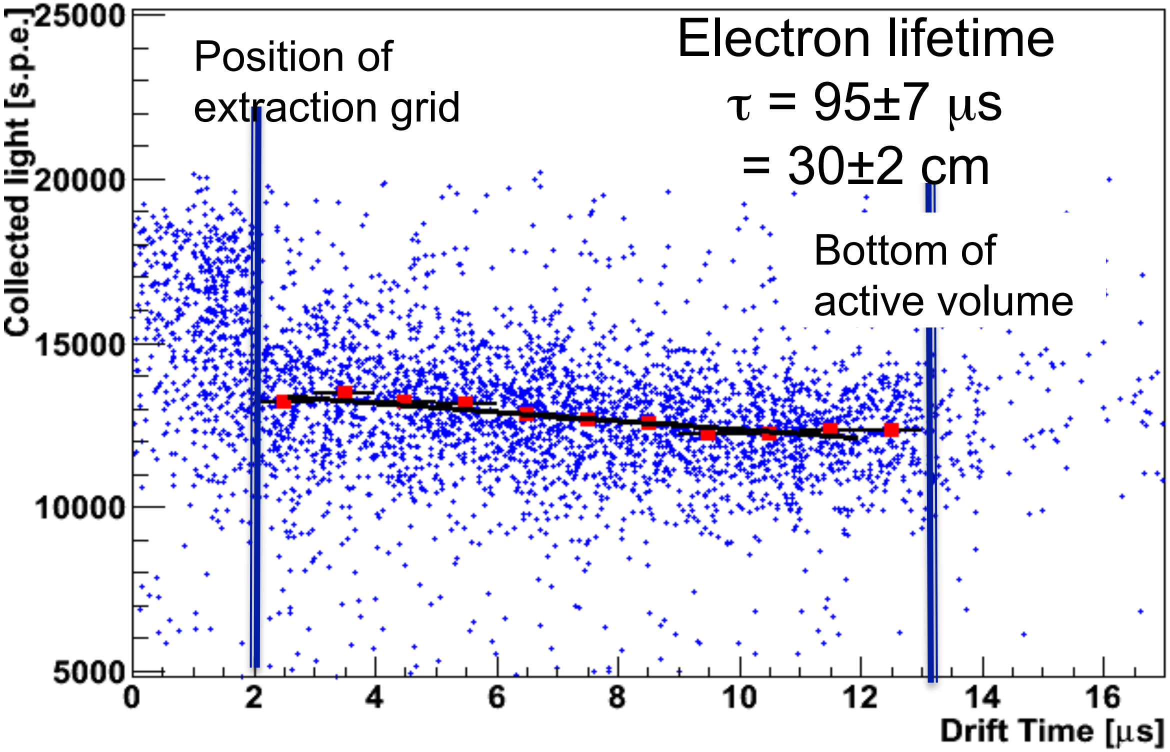
^{241}Am spectrum with fiducialization



(PMT1+PMT2) / (PMT3+PMT4)

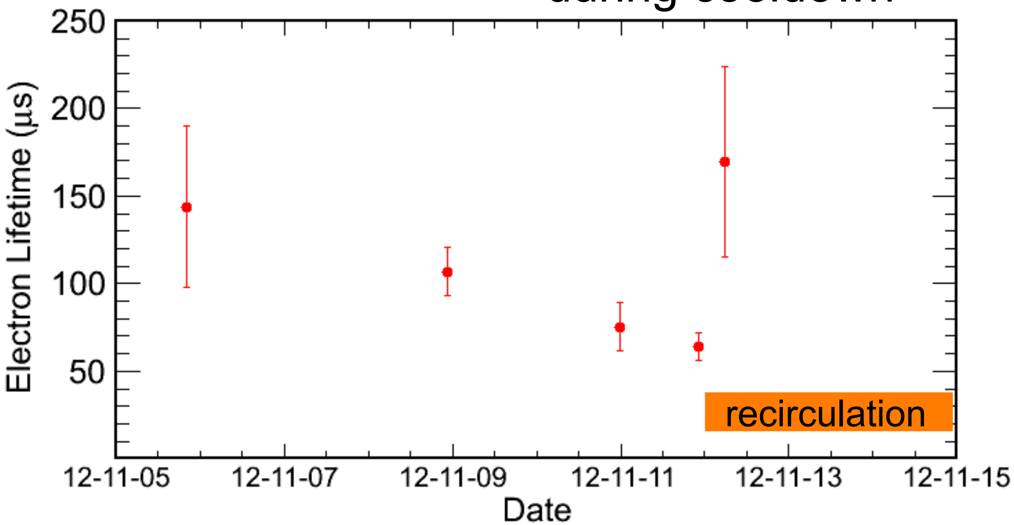
(PMT1+PMT3) / (PMT2+PMT4)

Long-lasting Argon Purity



Plot of S2 amplitude in ^{241}Am photopeak as a function of depth extracted from S1-S2 time

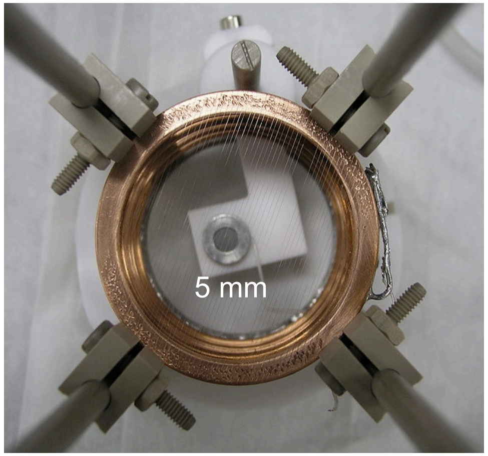
Electron lifetime during cooldown

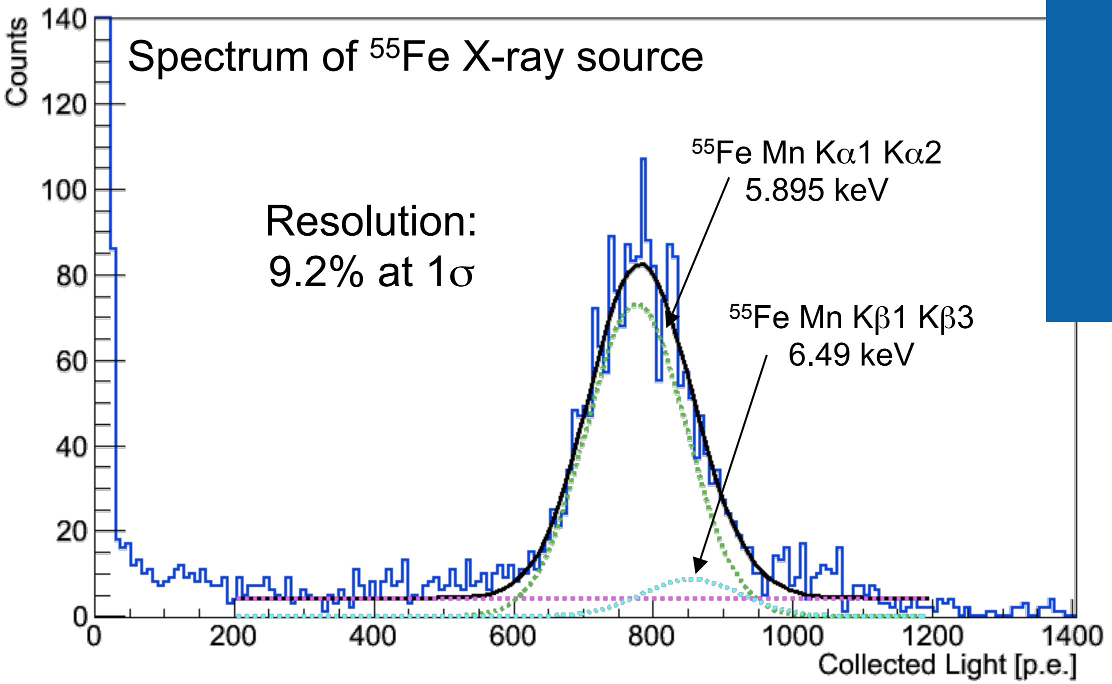


Recirculation needed only after ~6.5 days →

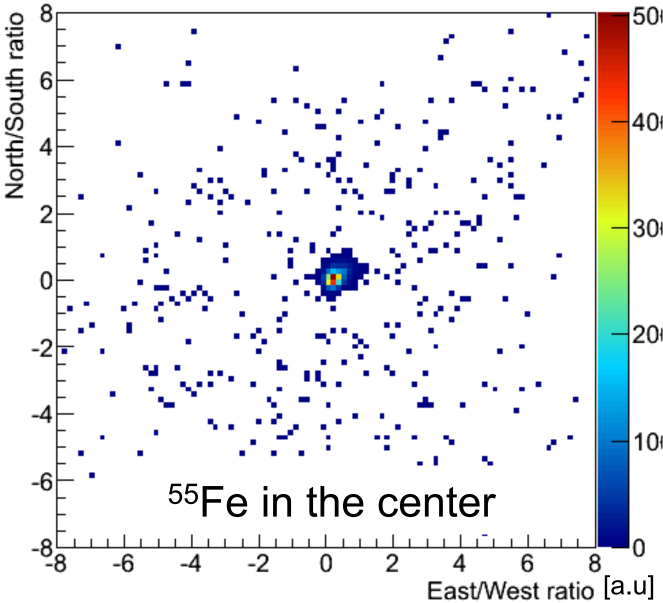
^{55}Fe Calibration

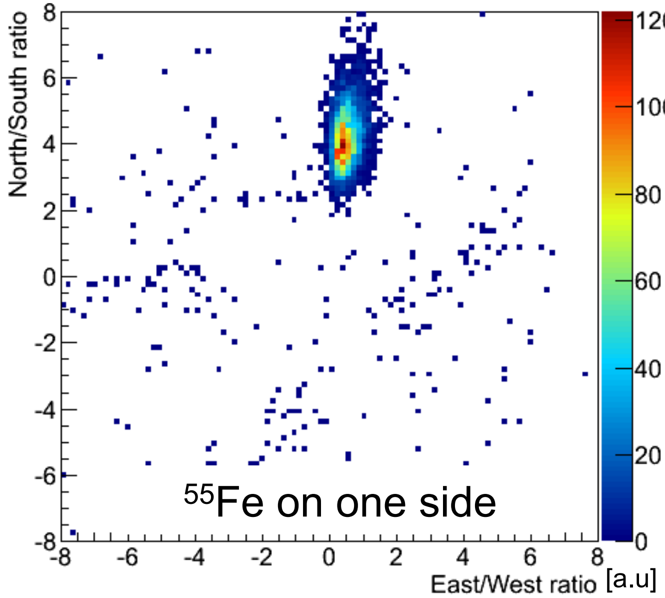
Electroplated ~100Bq
^{55}Fe on a movable arm





Under study:
- Mapping of fiducialization parameter space
- Position systematics





Novel Approach for Calibration: ^{37}Ar

Provides low-energy uniform calibration throughout the whole detector volume

Isotope production

Produced by neutron irradiation of ^{nat}Ar at a nuclear reactor

Decay scheme

100% electron capture

$t_{1/2}$ = 35.04 d

Q(gs) = 813.5 keV

Decay radiation

K- capture **2.82 keV** (90.2%)

L- capture 0.27 keV (8.9%)

M- capture 0.02 keV (0.9%)

^{nat}Ar isotopes

Mass number	Natural Abundance
40	99.6%
36	0.34%
38	0.06%

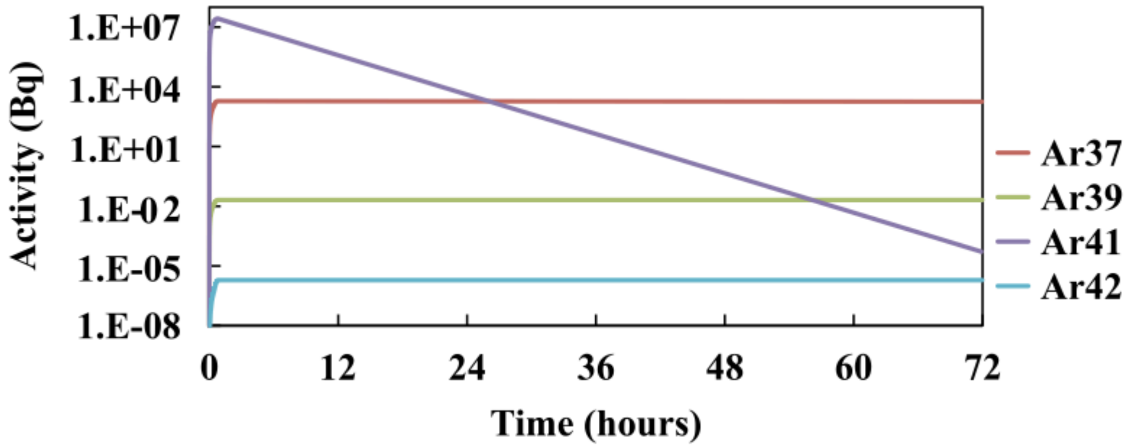


Fig. 1. Calculated activity of radioargon isotopes from 1 h, in-core neutron irradiation of 1 cm^3 of natural argon gas.

Barsanov, V. I. *et al. Phys. Atomic Nucl* **70** (2007).

Aalseth, C. E. *et al. NIM A***652**, 58–61 (2011).

Novel Approach for Calibration: ^{37}Ar

Provides low-energy uniform calibration throughout the whole detector volume

Isotope production

Produced by neutron irradiation of ^{nat}Ar at a nuclear reactor

Decay scheme

100% electron capture

$t_{1/2}$ = 35.04 d

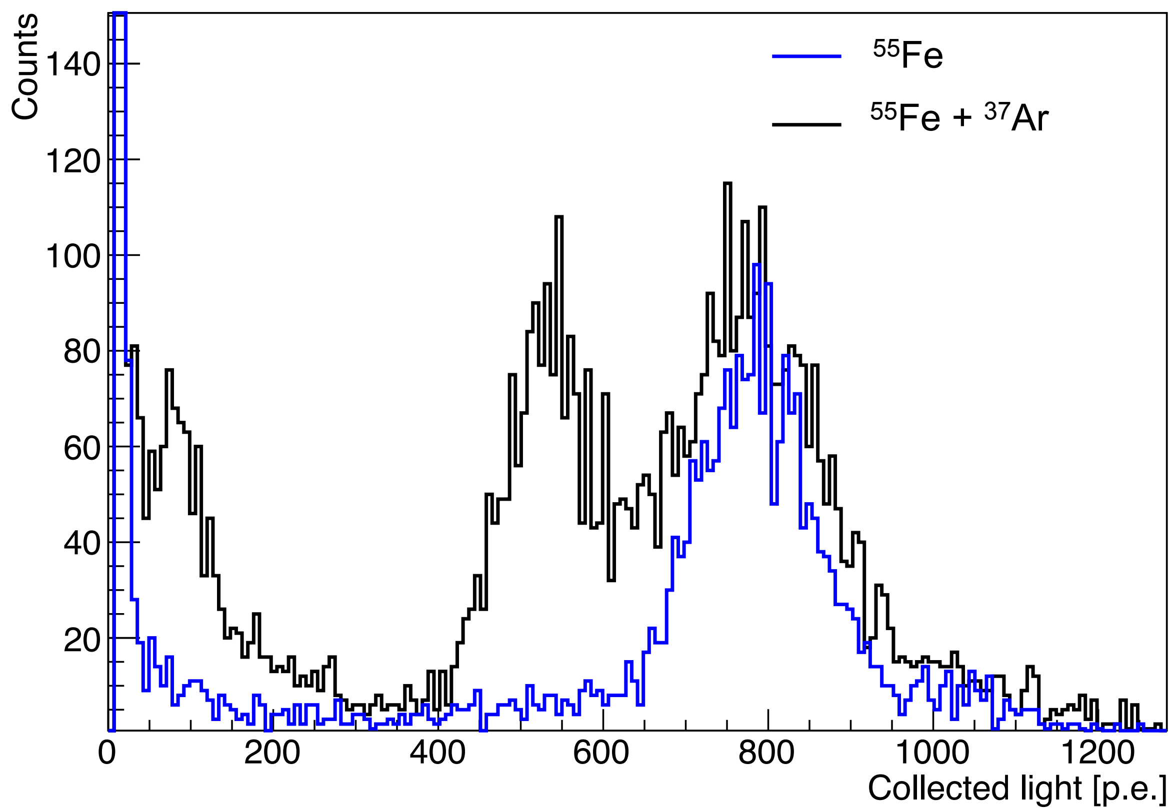
Q(gs) = 813.5 keV

Decay radiation

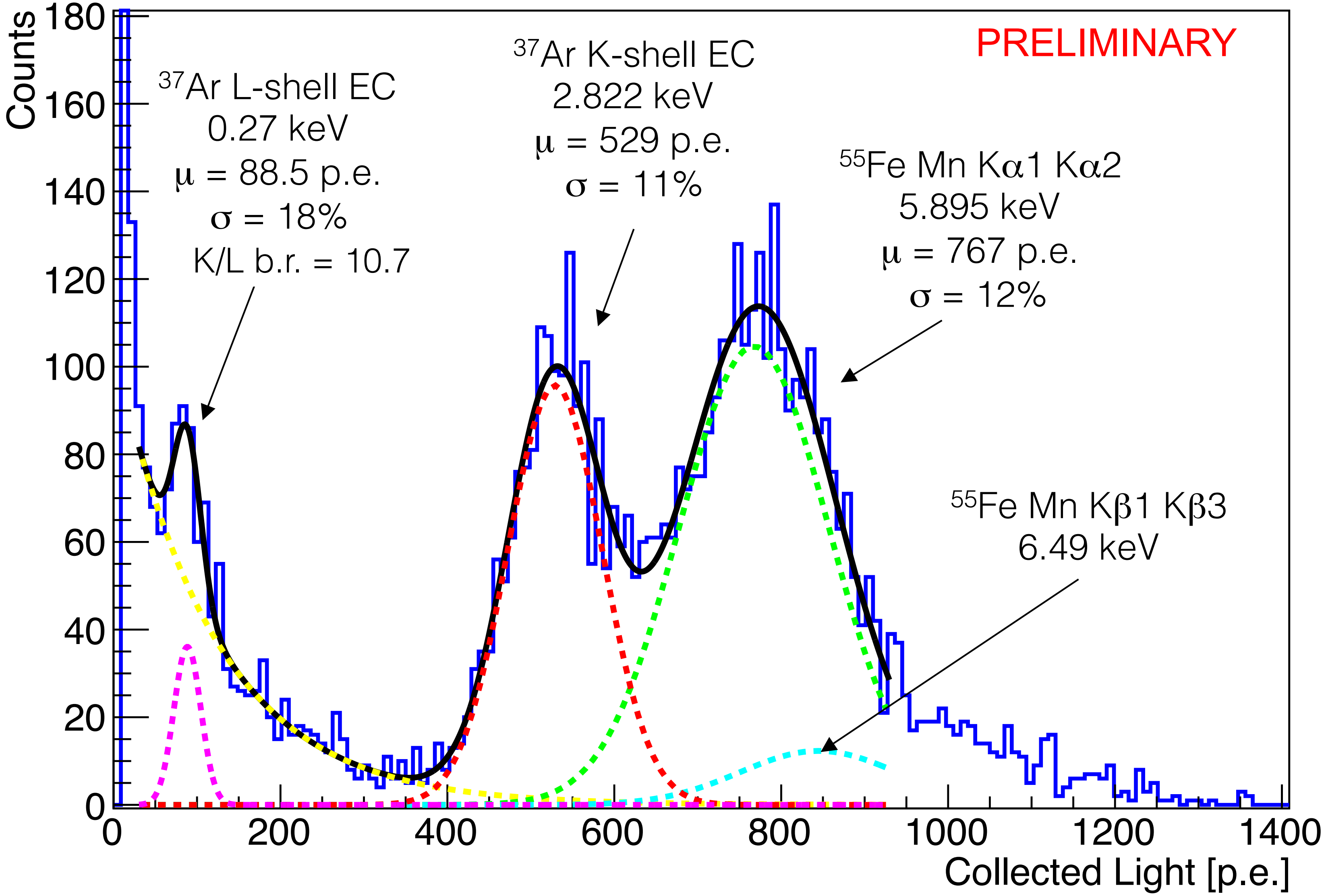
K- capture **2.82 keV** (90.2%)

L- capture **0.27 keV** (8.9%)

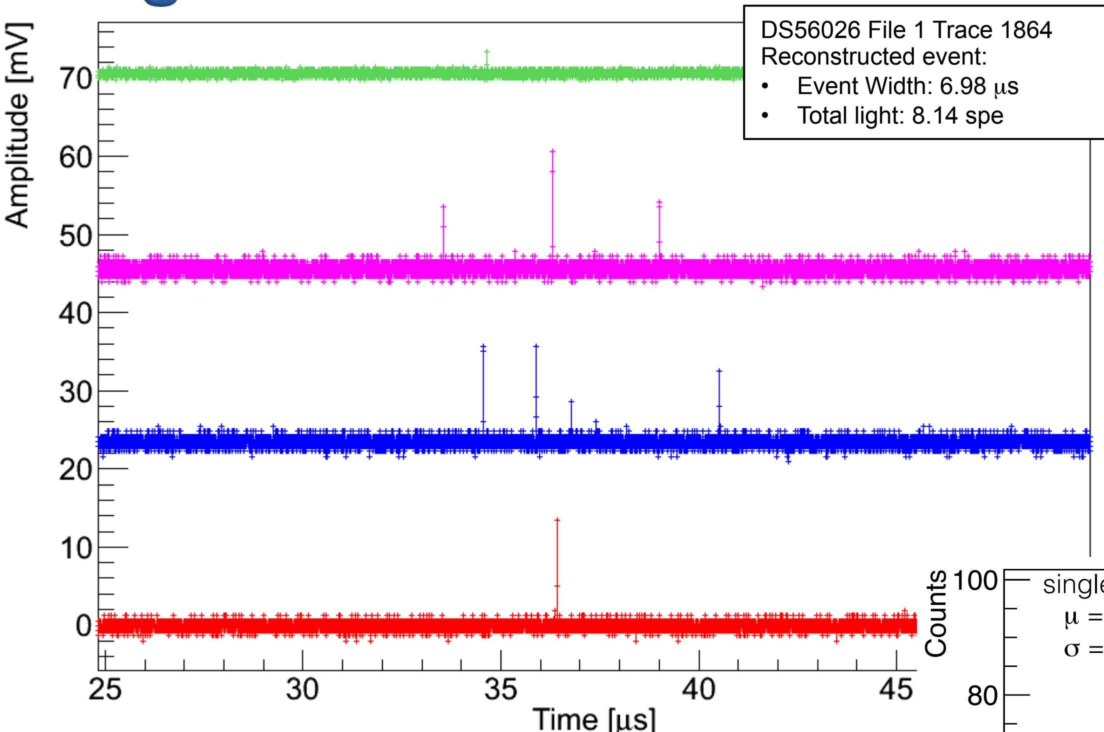
M- capture 0.02 keV (0.9%)



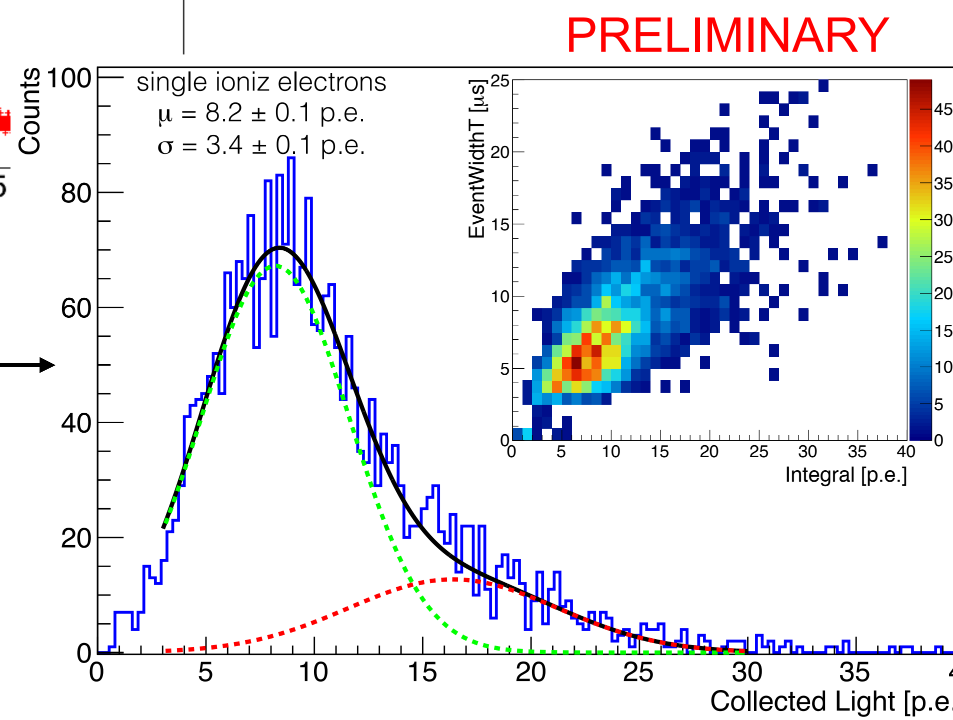
Sub-keV Sensitivity for Electron Recoils



Single Ionization Electrons



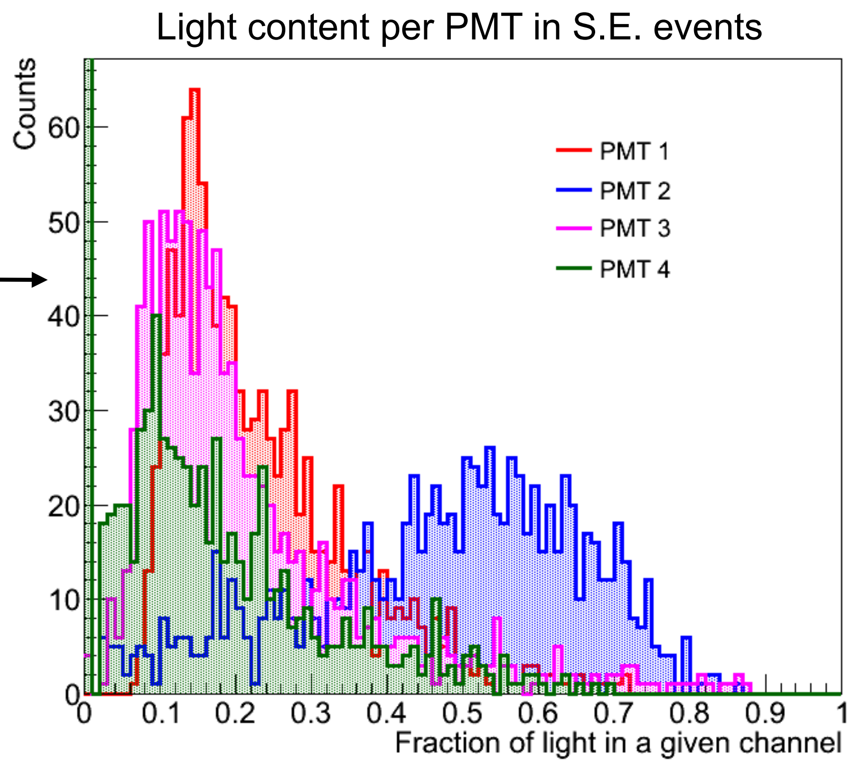
- Typical S.E. event as seen on the scope
- Full trace is 100µs long and has no s.p.e. other than those shown



- Experimental spectrum of single and double ionization electrons
- Not compatible with primary scintillation signal (S1) because:
  - Event width of 5-8 µs is too long
  - Light distribution not compatible with LAr S1 characteristics
  - Dependence on gain field

Single Electron Investigation in Progress

- S.E.s appearance has been seen in the aftermath of electrical discharges from the HV system, with rate decreasing with time
- S.E.s correlate with the presence of PTFE in the active region.
- Indications of S.E. production from a specific point in the detector from the light content per PMT



- Single Electrons:
  - Absolute detector calibration
  - Background for CNNS
  - Need to understand sources
  - Controlled production

Model of Ionization in Liquid Argon

Initial ionization from energy partitioning between ionization and excitation:

$$N_i = \frac{E_{er}}{w_q} \frac{1}{(1 + N_{\text{ex}}/N_i)}$$

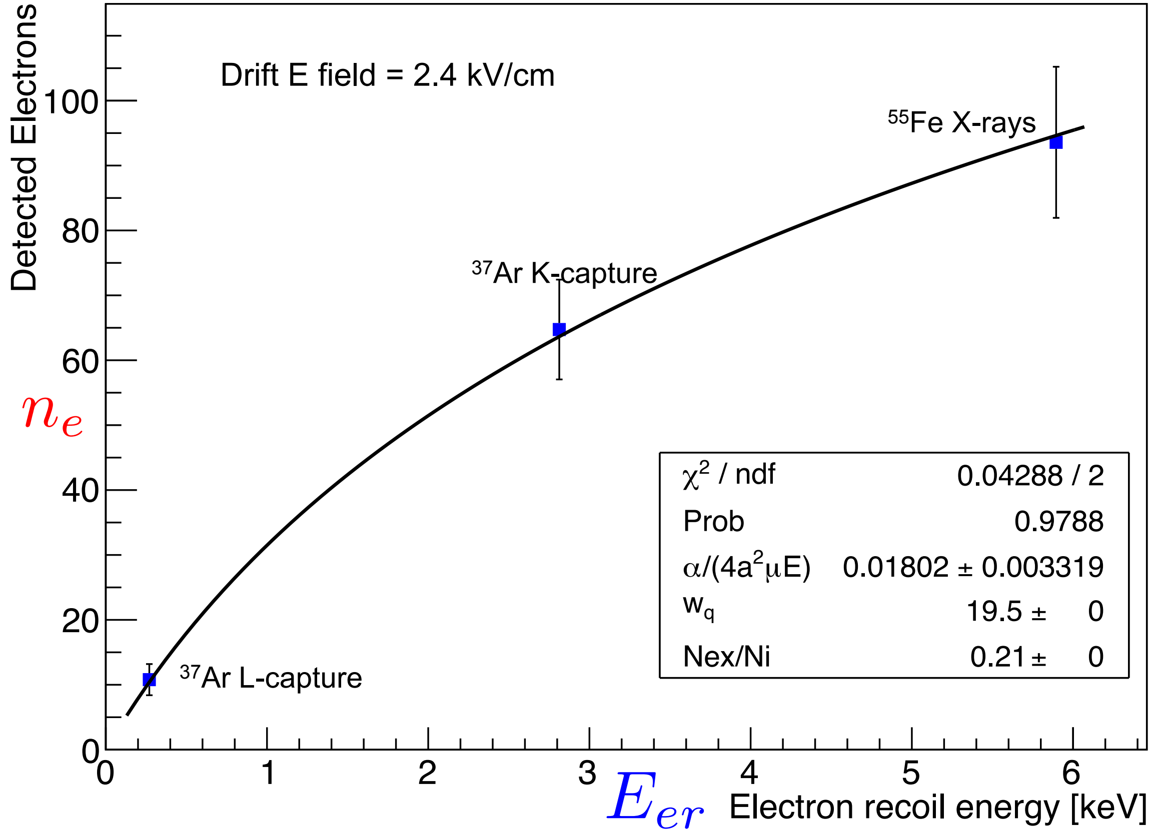
Assume Thomas-Imel box model of recombination:

$$\frac{n_e}{N_i} = \frac{1}{\xi} \ln(1 + \xi)$$

$$\xi = \frac{N_i \alpha}{4a^2 uE}$$

constant single fit parameter

PRELIMINARY



Cfr. Sorensen, P. and Dahl, C. E., *Phys. Rev. D.* **83** (2011)

Further discussions in M.Foxe and P. Sorensen talks

Future detector development

- Detector has capabilities to observe nuclear recoils > 2keVr for reasonable quenching values (> 0.1).
- Planned measurement at LLNL.
- Detector improvements are being considered to:
    - extend sensitivity to lower energies
    - reduce measurement uncertainties

More details in M.Foxe and T.Joshi talks

- Understanding of few-electrons processes is critical for CNNS (and Dark Matter)
- Need better single electron resolution
    - by reducing known detector systematics
    - by increasing production and/or collection of secondary light

Conclusions

- LLNL LAr detector:
  - Single electrons: achieved lowest detector sensitivity
  - Demonstrated sub-keV spectroscopy with LAr
- Ready to measure low energy nuclear recoils in LAr
  - determine ionization yield
  - key to assess CNNS feasibility
- Next:
  - Understanding and suppressing backgrounds in a large detector
  - CNNS detection!